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RATE OF FORMATION OF HONEYCOMB WEATHERING FEATURES (SMALL SCALE TAFONI) ON THE OTWAY COAST, S.E. AUSTRALIA

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Abstract: The development of honeycomb weathering on seawalls of nonmarine Lower Cretaceous greywacke built in 1943 and 1949 shows that under certain conditions this type of tafoni is a significant factor in the retrogradation of rocky coasts.

INTRODUCTION

Tafoni, as originally described by Bourcart (1930), consist of large cavities developed in the vertical faces and overhangs of granitic cliffs and tors in Corsica. The meaning has since been extended to include honeycomb weathering (e.g. Jennings 1968). Geikie (1882, p. 335) used the term "honeycombed". Thus tafoni in the modern sense can be divided into:

1. Cavitation weathering (in the sense of Bourcart), and
2. Honeycomb weathering.

Both occur in the nonmarine greywacke of the Otway coast of south eastern Australia. Although these two types are not mutually exclusive, they can usually be separated respectively in size (large, small), morphology (broadly rounded; groups of relatively steep-sided cells reminiscent of honeycomb), and loci of development (on cliffs and boulder bases; on all aspects including horizontal surfaces where cavitation weathering never develops). Cavitation structures on the coast may include an area of honeycomb.

TAFONI AND COASTAL RETROGRADATION RATE

The rate of coastal retrogradation varies according to the types of rocks forming them, and to the environments in which they stand. In the common environment (Mediterranean climate, microtidal, heavy swell) of the coast of Western Victoria, the rates of retrogradation of four rock types were found to vary by some orders of magnitude (Gill 1973a). As one of these rock types, the Otway greywacke, is affected to an exceptional degree by honeycomb weathering (Gill 1972, fig. 3), a means of quantifying this process was sought in order to assess its significance for coastal retrogradation. The best evidence was derived from stone retaining walls of known age that have developed a considerable amount of honeycomb weathering much more rapidly than previously estimated. The dates of construction of the walls were verified with the construction authority, and it was established that quarried stone (i.e. with fresh faces) was used.

Before the dated honeycombed walls were investigated (by N.H.M.), old photographs were examined for change, e.g. Jutson (1949, pl. 5, fig. 1), but the scale of these photographs and the lack of sufficient detail prevented adequate quantification. However, at Jutson's site 0.5 km S.W. of Point Grey, Lorne, six subspherical concretions shown in the 1949 photograph are now reduced to three and a half, a mass of protruding honeycomb has been broken away, and new honeycomb is developing on the fracture face.

HONEYCOMB FORMED SINCE 1943

Southwest of the mouth of St. George River on the Great Ocean Road, S.W. of Lorne, where a small perched rivulet crosses the road and drops to a boulder beach (Gill 1973b, pl. 6), a wall was constructed in 1943 to support the road (Pl. 10, fig. 1). The wall was built of fairly well squared blocks of greywacke from the Country Roads Board quarry

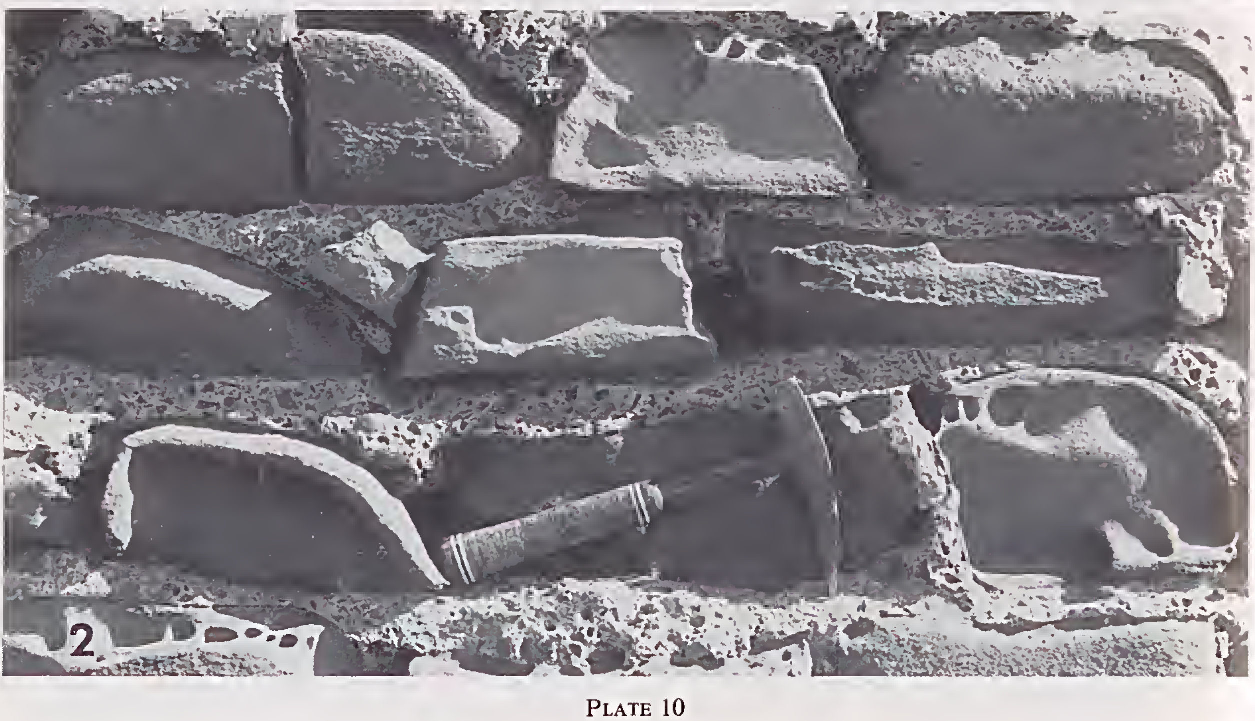

PLATE 10

in Lorne. Workmen inscribed their names in the wet cement at the time of building, *viz.* "S.A. Carr 1943" and "P.W. 1943". Honeycombed rock is not used for building walls, as can be seen in the rebuilt N.E. section of this wall, and in walls on the high side of the Great Ocean Road which escape this type of weathering. The N.E. part of this wall was washed away in a storm and had to be rebuilt. That considerable honeycomb weathering has developed since the wall was built in 1943 is also shown by:

1. The honeycomb formed in the cement as well as in the rock (Pl. 10, fig. 2).
2. Some cells have only a fine sliver of rock between cell and cement. Such a delicate structure could not of course be built into the wall.

HONEYCOMB FORMED SINCE 1949

The Great Ocean Road between Spout Creek (Eastern View) and Grassy Creek (Point Castries) includes an unstable area known as Clarke's Slip (Pl. 11, fig. 1). Clayey siltstone dips seaward at 40° oblique to the coast. The retrogradation rate of this siltstone is 100% greater than that of the accompanying greywacke, so the toe is more rapidly eroded. It is calculated that since the sea returned to its present level about 6,000 years ago in this area, the siltstone toe has retreated ~100 m but the accompanying greywacke toe only ~50 m. These are approximately the widths of the shore platforms in the respective lithologies. Where the siltstone outcrops, the shore is incurved. As slips here place the road in jeopardy, some control is necessary. In 1949 a wall was built at the toe of a slip to prevent it being eroded by the sea. It consisted of a double row of piles with rockfill. At the north (more protected) end, a short revetment wall was built of greywacke blocks from the Lorne quarry. This wall does not receive direct wave attack, but swash has eroded a nip at its base, and wave splash falls on the face above the nip. Recently, large masses of rock have had to be placed in front of the wall to protect the nip from further erosion (Pl. 11, fig. 1). All this honeycomb has developed in the past 30 years. The cells are more frequent and larger at the seaward end of the wall, showing that splash from the sea is a factor in its development. Walls built of the same rock on the same coast, but above the splash zone, have not developed honeycomb.

MODE OF HONEYCOMB FORMATION

The structures in the 1943 and 1949 walls throw light on the mode of formation of this type of weathering. Rocks *in situ* and the parts of the wall constantly washed by the sea are smooth, being subject to constant abrasion—the Schlictzone—whereas honeycomb occurs in the higher supratidal zone where the rocks are frequently wet by spray—the Spritzzone. The latter is between the top of the abrasion zone and the botton of the black alga *Verrucaria* zone. At Artillery Rocks the swash smooths the supratidal zone between carbonate concretions, but where pedestal rocks occur, honeycomb forms on the stems (Gill *et al.* 1977, pl. 9, fig. 1).

However, honeycomb weathering is not formed by marine action only, because one of the most spectacular developments of it is in the Swallows Cave on the Sheoak River at the site of a waterfall about a kilometre from the coast. As spindrift develops no honeycomb on stone walls on the Great Ocean Road not far above the shore, it cannot produce it in a river valley about 1 km inland with a rainfall about 1,000 mm p.a. In the same valley, small rare patches of honeycomb occur on cliffs and bluffs where pieces of rock have fallen away to leave fresh rock faces. The remaining rock surfaces are covered with a weathering crust. No such crust occurs on the honeycomb zone at the coast, but begins in the algal zone above, where it often domes, cracks, and produces scale. Some kind of intermittent wetting occurs at all honeycomb sites. Some claim that salt (NaCl) is the sole agent, but S.E.M. examination (see below) and the occurrence of very well developed honeycomb at sites like the Swallows Cave rule this out for the Otway region.

As shown in the figures, different blocks in the same stone wall are affected to different degrees by honeycomb weathering, indicating that there is some lithologic control (as well as degree of wetting) of the process. Many blocks are subject to perimeter weathering. Often the honeycomb cells are aligned with joint planes, which suggest that stresses set up in the strata during tectonic movement have developed preferential orientations in the matrix of the rock.

PLATE 10

FIG. 1—Seawall of quarried greywacke built in 1943 on the Great Ocean Road S.W. of St. George River, Lorne district, Victoria. Note the "nip" at the base of the wall, and the honeycomb weathering.

FIG. 2—Detail of honeycomb weathering on wall face. The concrete cement is also weathered.

With the help of Dr. C. M. Barton, the length versus width of cells was checked on an image analyzer to quantitatively determine the degree of elongation in the vicinity of a major joint. The ratios in three samples were 0.63, 0.70, and 0.72 respectively.

SCANNING ELECTRON MICROSCOPE EXAMINATION

ERS and EDG spent a considerable time examining both weathered and fresh (broken) faces of greywacke in which honeycomb has developed. These faces present a strong contrast. In the former the quartz grains are bared, they stand out from the surface of the rock, and are often bounded by cracks showing that they are in process of being released. Secondary minerals on the surface of the rock are characteristic. Two types are dominant—carbonates and clays. Calcite was determined in a secondary coating on quartz grains in many places. The secondary clay minerals were also present as coatings, but in addition occurred as crystals, viz. small (~5μm), numerous crystals standing up above the surface of the rock. Weathered felspars were recognized. One series of SEM examinations showed minute (5-10μm) gypsum crystals ('flowers') as well as crystalline calcite on the weathered surface. Halite crystals were found in only one place and they were on the surface of rock, not in crevices where their growth could prise grains apart.

By contrast, the fracture surface shows the grains to be covered by clay skins, and in places there are smooth clay surfaces interpreted as casts of grains. Many pores in the rock are filled with platy clay deposits, and an interstitial zeolite was noted. The secondary minerals seen on the weathered surface are absent. Both the weathered and fracture surfaces show the rock to be porous. The quartz grains are angular to rounded. Bradley *et al.* (1978) found that salts are significant in forming cavitation weathering on inland granites in South Australia.

The above results are consistent with the petrographic description of Otway greywacke. Laumontite has been recorded in these rocks, and is probably the zeolite noted. The presence of gypsum fits the observation of secondary pyrite both as platy deposits in joints, and as nodules (Gill *et. al.* 1977). The whole formation is rich in carbonates that constitute two generations:

(a) Penecontemporaneous concretions, pre-tectonic.
(b) Post-tectonic joint deposits.

The porosity noted in the rock would allow easy migration of the solutions from which the secondary minerals were precipitated.

CONCLUSIONS

Under favourable conditions, honeycomb weathering can develop rapidly enough to be a significant factor in coastal retrogradation. It is estimated that tafoni accounts for ~10% of the coastal erosion of the Otway Group greywacke in S.E. Australia.

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Plate 11

Fig. 1—Greywacke revetment to piled structure built in 1949 at Clarke's Slip between Spout Creek and Point Castries on the Great Ocean Road at Eastern View, Victoria. The wall has been so weakened by honeycomb weathering that the large rocks in the foreground have been emplaced to protect the wall. The tide is high and the sea exceptionally calm.

Fig. 2—Detail of the honeycomb weathering. The wall is in the marine splash zone.

Plate 12

Calcite concretion (without honeycomb weathering) on greywacke pedestal with strongly cellular honeycomb which is being eroded at the base by swash. The sea is to the right. The molluscs are *Littorina*, which inhabit the splash zone. Artillery Rocks, Otway coast, Victoria.

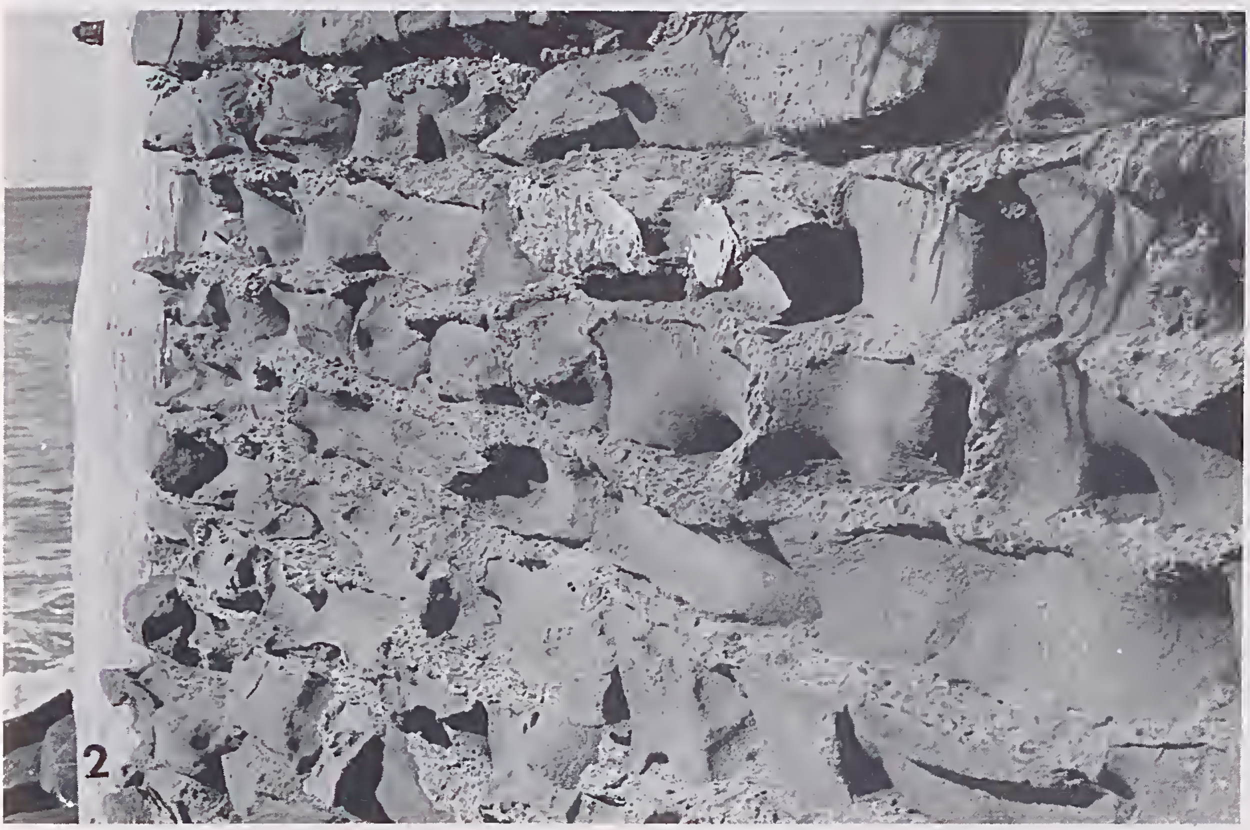

PLATE 11

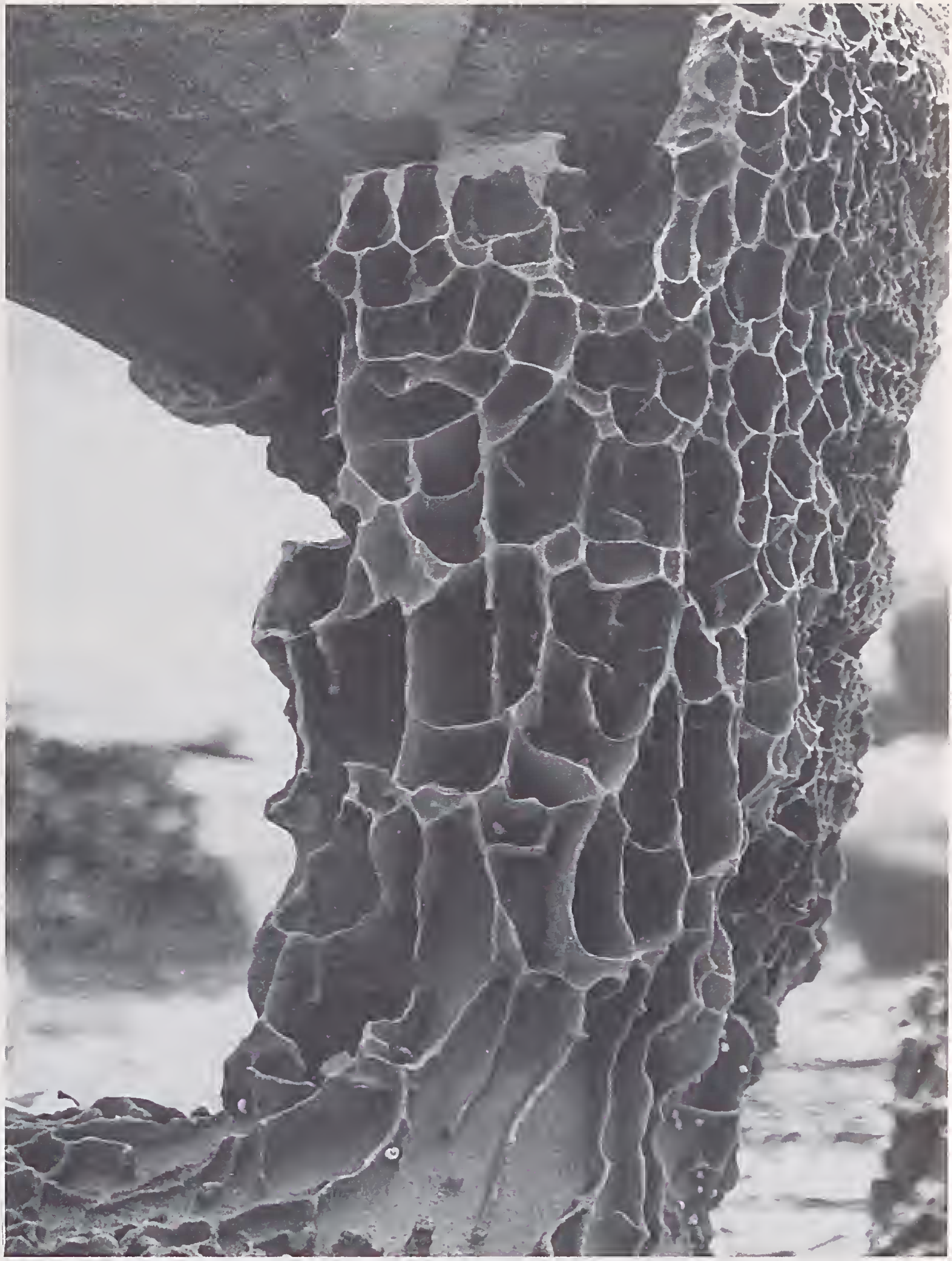

PLATE 12